THE EFFECT OF SECOND THROAT GEOMETRY ON THE PERFORMANCE OF EJECTORS WITHOUT INDUCED FLOW

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ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

NOTICES

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AFSC Program Area 750G, Project 6950, Task 69501
ARO Project No. 100928

Contract No. AF 40(600)-800 S/A 24(61-73)

ABSTRACT

An investigation of ejectors without induced flow was made to determine the effects of second throat geometry and position on the starting and operating pressure ratios. Twenty-seven ejector configurations were tested using three 18-deg half angle conical nozzles and one contoured nozzle in combination with six, second throat configurations. Unheated air was used for all tests.

The starting and operating pressure ratios were improved by the presence of a second throat. Second throat contraction ratio and length of minimum area had the greatest influence on the starting and operating pressure ratios. The limiting second throat contraction ratio determined in this investigation agrees with published NASA results, although the ejector geometries were considerably different.

Two methods are presented for estimating the operating pressure ratio of second throat ejector configurations.

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NOMENCLATURE

A	Cross-sectional area
D	Diameter
L	Length
M	Mach number
p	Static pressure
p_{pt}	Nozzle plenum total pressure
$p_{t_{ex}}$	Total pressure at cylindrical duct exit
T_t	Nozzle plenum total temperature
X	Distance between nozzle exit and second throat inlet
θ_n	Nozzle divergence angle at nozzle exit
θ_{st}	Second throat inlet angle (Fig. 1)
θ_e	Second throat exit angle (Fig. 1)

SUBSCRIPTS

c	Ejector cell
d	Duct
ex	Exhaust
exp	Experimental
min	Minimum
max	Maximum
ne	Nozzle exit
opt	Optimum
st	Second throat minimum area section

SUPERSCRIPTS

*	Nozzle throat

INTRODUCTION

This report presents the results of Phase V of an ejector research program being conducted in the Rocket Test Facility (RTF), Arnold Engineering Development Center, Air Force Systems Command (AFSC). The subjects covered by the other phases of this research program may be summarized as follows:

Phase I: Effect of nozzle area ratio and diffuser size on the performance of ejectors equipped with 18-deg half angle conical nozzles (Ref. 1)

Phase II: Effect of conical inlets on the performance of ejector systems similar to those studied in Phase I (Ref. 2)

Phase III: Effect of diffuser length on the performance of ejector systems similar to those studied in Phase I (Ref. 3)

Phase IV: Effect of nozzle plenum total pressure level on the performance of ejector systems similar to those studied in Phase I (Ref. 4)

The purpose of the Phase V investigation was to determine the influence of a second throat on the performance of ejector systems similar to those studied in the Phase I investigation. Of particular interest was the question of whether or not the second throat would improve (increase) the starting and operating pressure ratios of the ejector system as in the case of supersonic wind tunnels.

Other investigators (Refs. 5 and 6) have studied experimentally the influence of second throat geometry on the performance of ejector systems. The data presented in Ref. 5 were obtained from ejector systems having the cylindrical duct diameter nearly equal to the nozzle exit diameter. The data presented in Ref. 6 were obtained from ejector systems which used an axisymmetric nozzle exhausting into a rectangular diffuser containing a two-dimensional second throat. In the present investigation, the ejector systems studied were made up of an axisymmetric nozzle located concentric with a cylindrical duct having a diameter significantly greater than the nozzle exit diameter. The following test conditions and geometric parameters were varied:

1. Second throat location, X
2. Nozzle plenum total pressure level, p_{pt}

Manuscript released by authors September 1961.

3. Second throat inlet angle, θ_{st}
4. Second throat exit angle, θ_e
5. Second throat contraction ratio, A_{st}/A_d
6. Second throat minimum area length, L_{st}
7. Nozzle area ratio, A_{ne}/A^*
8. Nozzle exit angle, θ_n
9. Area of duct to area of nozzle throat, A_d/A^*

The data were obtained during the period December 6, 1960, to March 23, 1961.

APPARATUS

The twenty-seven ejector configurations tested were composed of an axisymmetric nozzle concentrically located in a sealed plenum section with a straight cylindrical diffuser containing a movable conical converging and diverging second throat. A typical test configuration is shown in Fig. 1.

The four supersonic nozzles used (expansion ratios, A_{ne}/A^*, of 3.63, 10.85, 23.68, and 25.0) were each made of brass and machined in one piece. Dimensional details of these nozzles are presented in Table 1, and typical nozzle configurations are shown in Fig. 2.

The eight, second throat configurations (contraction ratios, A_{st}/A_d, of 0.8, 0.654, 0.5, and 0.398) were of the conical type and were obtained by modifying the conical inlets used in the Phase II investigation. Only the second throat configuration having a contraction ratio of 0.398 was specifically fabricated for this investigation. The dimensional details of each second throat configuration are presented in Table 1.

The location of the second throat configurations which had a 90-deg exit angle could be manually varied during a test by using rods attached to the downstream surface, as shown in Fig. 1.

Each second throat ejector system tested included a cylindrical duct having an inside diameter of 6.02 in. and a length to diameter ratio of approximately 9.0 without a subsonic diffuser.

Included in Table 1 are the configuration code designations of the nozzles and second throats. A typical second throat ejector configuration

designation would be 5-2a meaning nozzle configuration 5 and second throat configuration 2a. The geometry would be as follows:

$$A_{ne}/A^* = 23.68$$

$$\theta_{st} = 12 \text{ deg}$$

$$\theta_e = 90 \text{ deg}$$

$$A_{st}/A_d = 0.8$$

$$L_{st}/D_{st} = .343$$

Ejectors without a second throat are designated only by the nozzle configuration code.

For each test the parameters measured were: cell pressure, p_c; exhaust pressure, p_{ex}; nozzle plenum total pressure, p_{pt}; nozzle exit static pressure, p_{ne}; and nozzle plenum total temperature, T_t. In Table 2, the type of measuring instrument and the estimated maximum deviation within the measured range is presented for each parameter measured.

PROCEDURE

Before each test the entire cell was pressure checked with 30-psia air, and all flanges and instrumentation fittings were sprayed with liquid soap to permit detection of any possible leak. In addition, the instrumentation was evacuated to 30 mm Hg to check for leakage.

For each test configuration, the objective was to determine the minimum cell pressure ratio, (p_c/p_{pt}), and the corresponding starting and operating pressure ratios, (p_{ex}/p_{pt}), for various locations of the second throat. A typical ejector performance curve defining the starting and operating pressure ratios is presented in Fig. 3. The data were obtained by first setting the desired nozzle plenum total pressure level with the exhaust pressure low enough to insure ejector starting and then increasing the exhaust pressure until the ejector became unstarted which point determined the operating pressure ratio. The exhaust pressure was then decreased until the ejector became started, which point determined the starting pressure ratio. This procedure was repeated for various locations of the second throat. For each ejector configuration, data were obtained for nozzle plenum total pressures of 40 and 20 psia. The test conditions for all configurations are presented in Table 3.

RESULTS AND DISCUSSION

EXPERIMENTAL RESULTS

A complete tabulation of the experimental results is presented in Table 3. Included are nozzle plenum total pressure, nozzle plenum total temperature, the location of the second throat, the minimum cell pressure ratio, the nozzle exit static pressure, the required starting pressure ratio, and the maximum operating pressure ratio.

The variation of ejector performance with nozzle plenum total pressure level and the various geometric parameters of the second throat are discussed in the following analysis of the experimental data.

Hysteresis of Starting Pressure Ratio

The starting and operating pressure ratios are shown in Table 3 to be essentially equal, and this was true for all second throat ejector configurations tested. A slight hysteresis did occur when the second throat was located near the downstream point at which it became impossible to restart the ejector system when a minimum exhaust pressure of 0.2 psia was used.

Effect of Second Throat Location on the Starting and Operating Pressure Ratios and on the Minimum Cell Pressure Ratio

A typical variation of minimum cell pressure ratio and starting pressure ratio with second throat location is shown in Fig. 4. The range of second throat locations which do not influence the minimum cell pressure ratio is bounded at the upstream end, $(X/D_d)_{min}$, by the increase in minimum cell pressure ratio and at the downstream end, $(X/D_d)_{max}$, by the inability to start the ejector system.

The initial increase in minimum cell pressure ratio as the second throat was moved upstream of $(X/D_d)_{min}$ is caused by the free jet impinging on the contracting portion of the second throat. This increases the static pressure rise through the impingement zone and results in an increase in the minimum cell pressure ratio (Ref. 7). The result is consistent with the decrease in minimum cell pressure ratio produced by a conical inlet which causes the static pressure rise through the impingement zone to decrease (Ref. 2).

A comparison of experimentally determined $(X/D_d)_{min}$ locations of the second throat with theoretical jet impingement points from Ref. 3 is

presented in Fig. 5. For all second throats having inlet angles of 6 or 12 deg, $(X/D_d)_{min}$ was always downstream of the theoretical jet impingement point by 0.020 to 0.20 duct diameters. The second throat configurations having inlet angles of 18 deg usually had $(X/D_d)_{min}$ values within this range except in the case of ejector configuration 1-4a which, because of the relatively low duct Mach number (based on A_D/A^*), caused the duct boundary layer to separate (Ref. 8), thus moving the $(X/D_d)_{min}$ downstream of the theoretical jet impingement point by 0.4 duct diameters. Figure 5 also shows that, for unknown reasons, an increase in the throat length of the second throat to 8.0 throat diameters allows the second throat to be located nearer the theoretical jet impingement point for a given second throat contraction ratio.

The value of $(X/D_d)_{max}$ of each second throat configuration was experimentally determined based on ability to start the ejector system. Figure 6 presents the duct length $[(X/D_d)_{max} - (X/D_d)_{min}]$ within which a second throat may be located without influencing the minimum cell pressure ratio. This duct length $[(X/D_d)_{max} - (X/D_d)_{min}]$ decreases sharply as the second throat contraction ratio is decreased from 0.65 to 0.4.

The optimum location of a second throat must lie within the range of duct length $[(X/D_d)_{max} - (X/D_d)_{min}]$ since the second throat must not influence the minimum cell pressure ratio. It is also necessary to locate the second throat at a position at which the starting pressure ratio, p_{ex}/p_{pt}, is a maximum. Figure 4a and the other data presented in Table 3 show the starting pressure ratio to be nearly constant for all second throat locations within the duct length range $[(X/D_d)_{max} - (X/D_d)_{min}]$ with the maximum starting pressure occurring at or slightly downstream of the $(X/D_d)_{min}$ location. However, for some configurations such as 3-4a a second optimum location existed further downstream.

Effect of Nozzle Total Pressure Level

In Ref. 4 the effect of nozzle total pressure on the starting and operating pressure ratios of ejectors without second throats is shown to be negligible although the minimum cell pressure ratio varies considerably. This is also true for ejectors using second throats, as shown in Fig. 4, if the second throat is located where it does not affect the minimum cell pressure ratio. Since the free jet impingement point is a function of the minimum cell pressure ratio, the optimum second throat location is, therefore, a function of the nozzle total pressure level.

Effect of Second Throat Inlet Angle, θ_{st}, on Starting and Operating Pressure Ratios

Figure 7 shows the starting and operating pressure ratios obtained from ejectors equipped with second throats having inlet angles of 6, 12, and 18 deg and unequal minimum area lengths of less than one throat diameter. Based on the data presented in Ref. 5, the inequality of the minimum area lengths is not a factor in this comparison. The starting and operating pressure ratios were essentially independent of the second throat inlet angle for inlet angles within the range of 6 to 18 deg. However, a small second throat inlet angle is necessary to prevent boundary-layer separation which has a strong influence on the optimum location of the second throat.

Effect of Second Throat Exit Angle, θ_e, on Starting and Operating Pressure Ratios

Second throat configuration 4-1b had an exit angle of 18 deg; all other second throat configurations had exit angles of 90 deg. When the results of the testing of configuration 4-1b are compared with results obtained from testing configuration 4-1a, the second throat exit angle is shown to have a negligible influence on the starting and operating pressure ratio. The second throat configurations used in this comparison had very short minimum area lengths.

Effect of Second Throat Contraction Ratio on Ejector Performance

The variation of ejector performance with second throat contraction ratio, (A_{st}/A_d), is best assessed by comparing the performance of the same ejector system without a second throat. For this comparison, an optimum second throat location was selected from plots of the data presented in Table 3. Figures 8a and b show the variation in the relative starting pressure ratio and the relative minimum cell pressure ratio, respectively, with second throat contraction ratio. All second throat configurations improved (increased) the ejector starting and operating pressure ratios, and the improvement increased as the contraction ratio was decreased. A further increase of approximately 30 to 40 percent in the starting and operating ejector pressure ratios can be accomplished by increasing the length of the minimum area of the second throat, as shown by the closed symbols in Fig. 8a.

Only one second throat ejector system was tested using a contoured nozzle (Config. 5-3b). The improvement in the starting and operating pressure ratios shown in Fig. 8a for this ejector system indicates that a

second throat will produce a greater improvement in the starting and operating pressure ratios of an ejector system having a contoured nozzle than of one having an 18-deg conical nozzle.

The criteria for determining the limiting second throat contraction ratio for an ejector system can be defined as the minimum contraction ratio which causes no increase in minimum cell pressure ratio when the second throat is at the optimum location. The variation of the relative minimum cell pressure ratio with second throat contraction ratio shown in Fig. 8b can be used to estimate the limiting contraction. In Ref. 5 a limiting second throat contraction ratio curve is presented for ejector systems having cylindrical duct diameters slightly larger than the nozzle exit diameter and long minimum area second throat configurations. The data from the present investigation obtained using ejector systems having a cylindrical duct diameter much greater than the nozzle exit diameter agree very well with the limiting curve from Ref. 5, as shown in Fig. 9. However, the limiting curve from Ref. 5 is not necessarily valid for second throat configurations having very short minimum area lengths, as shown by comparing ejector configurations 4-3a and 4-3b (contraction ratio 0.5) in Fig. 9. Included in Fig. 9 is the limiting second throat contraction ratio determined by the well known normal shock method. This limiting contraction ratio curve is shown to be very conservative for ejector systems.

A most unusual result of this investigation is the decrease in minimum cell pressure ratio caused by the presence of a second throat. The magnitude of this decrease in the case of configurations 3 and 4 is shown in Fig. 8b to be a function of nozzle exit flow conditions, second throat contraction ratio, and the second throat minimum area length. These phenomena cannot be explained quantitatively or qualitatively and contradict all existing theoretical analyses.

THEORETICAL ANALYSIS

The object of the following analysis is to devise a simple method of estimating the operating pressure of second throat ejector systems similar to those experimentally studied in this investigation. Such a method would be particularly valuable in designing second throat ejector systems using any type of driving fluid.

Two simple methods are described:

Method A is based on the following assumptions:

1. The ratio of specific heats of the driving fluid is constant.
2. All losses occur in the second throat.

3. The Mach number at the entrance to the second throat is defined by the ratio of duct area to nozzle throat area and isentropic one-dimensional flow.

4. The Mach number decreases isentropically through the converging portion of the second throat.

The estimated operating pressure ratio is then the total pressure loss through a normal shock wave based on the Mach number at the minimum area of the second throat. A comparison of the calculated operating pressure ratio obtained by this method with experimental results is presented in Fig. 10. As shown, the normal shock method is in error by a factor of 1.3 to 2.0 for all configurations tested as the second throat contraction ratio approaches the limiting value.

Another method of estimating the operating pressure ratio of second throat ejector systems (Method B) is presented in Ref. 9. Basic assumptions 1, 2, and 3 of Method A are retained and the additional assumption is made that sonic Mach number exists at the minimum area of the second throat. The operating pressure ratio is then the total pressure loss obtained by applying the continuity relationship for adiabatic one-dimensional flow between the nozzle throat and the minimum area of the second throat. The equation is

$$p_{t_{ex}}/p_{pt} = A^*/A_{st} \qquad (1)$$

A comparison of the calculated operating pressure ratio obtained by this method with the experimental results is also presented in Fig. 10. The maximum error of this method as the second throat contraction ratio approaches the limiting value is about 30 percent except for second throat configurations having a long minimum area section, in which case the error is much smaller.

Either Method A or B can be used in the design of second throat configurations for ejector systems by using Fig. 10 to determine the necessary correction factor. However, these methods cannot be used to determine the limiting second throat ratio; instead this can be obtained from Fig. 9.

SUMMARY OF RESULTS

The results of the investigation to determine the effects of second throat geometry and nozzle plenum total pressure level on ejector performance can be summarized as follows:

1. The starting and operating pressure ratios were equal (no hysteresis) for all ejector configurations tested with the second throat at the optimum location.

2. The starting and operating pressure ratios were improved to 20 to 30 percent by the presence of a properly located second throat; the improvement increased as the limiting second throat contraction ratio was approached. Increasing the length of the minimum second throat area section further improved (by 30 to 40 percent) the starting and operating pressure ratios of the ejector systems tested. The improvement was greatest for the ejector system which had a contoured nozzle. Second throat inlet angles of 6 to 18 deg and exit angles of 18 and 90 deg did not influence the starting and operating pressure ratios of the ejector systems having second throats with very short minimum area sections.

3. The limiting second throat contraction ratios indicated by this investigation verify the limiting second throat contraction ratio curve published by NASA for long minimum area second throat configurations although the ejector systems studied in this investigation differed considerably from those studied by NASA.

4. The experimental results of this investigation indicate the optimum second throat location to be approximately 0.02 to 0.2 cylindrical duct diameters downstream of the free jet impingement point. The optimum location becomes very critical as the limiting second throat contraction ratio is approached.

5. Two simple methods are presented for estimating the operating pressure ratio of second throat ejector systems. One is based on an isentropic decrease in Mach number between the entrance and the minimum area of the second throat followed by a normal shock wave at the minimum area; the other is based on the continuity of mass between the nozzle throat and the minimum area of the second throat. The method based on continuity of mass is the most accurate overall and is especially accurate for long minimum area second throat configurations.

6. Nozzle total pressure level did not influence the ejector starting or operating pressure ratios but did influence the minimum cell pressure ratio. Since the free jet impingement point is a function of the minimum cell pressure ratio, the optimum second throat location is, therefore, a function of the nozzle total pressure level.

7. For some ejector systems equipped with a second throat, the minimum cell pressure ratio was slightly lower than the minimum cell pressure ratio obtained from the same ejector system when no second throat was used. The reason for this is unknown.

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TABLE 1

DESCRIPTION OF NOZZLES AND SECOND THROATS

Nozzle Dimensions				
Nozzle** Config	A_{ne}/A^*	D^*, in.	D_{ne}, in.	θ_n, deg
1	3.627	2.200	4.190	18°
3	10.848	1.262	4.155	18
4	25.000	0.831	4.155	18
5	23.684	0.900	4.380	0
Est Max Deviation		±0.001	±0.001	±0.5

Second Throat Dimensions				
Config Code	θ_{st}, deg	θ_e, deg	A_{st}, A_d	L_{st}/D_{st}
1a	6	90	.654	0.431
1b	6	18	.654	0.807
2a	12	90	.800	0.343
2b	12	90	.568	0.331
3a	12	90	.500	0.690
3b	12	90	.500	8.000
3c	12	90	.398	0.518
4a	18	90	.654	0.376
Est Max Deviation	±0.5	±0.5		

D_d = 6.02 in.; L_d/D_d = 9.1

**Same Code as Ref. 3

TABLE 2

ESTIMATED MAXIMUM DEVIATIONS OF THE MEASURING INSTRUMENTS

Parameter Measured	Range Measured	Measuring Instrument	Max Deviation
p_c	0.2 to 5mm HgA	McLeod (with nitrogen cold trap)	
	5 to 50mm HgA	diaphragm-activated dial gage	±0.05mm HgA
p_{ex}	7 to 50mm HgA	diaphragm-activated dial gage	±0.05mm HgA
	1 to 10 psia	diaphragm-activated dial gage	±0.25mm HgA
p_{pt}	1 to 46 psia	diaphragm-activated dial gage	±0.25mm HgA
p_{ne}	1 to 50mm HgA	diaphragm-activated dial gage	±0.05mm HgA
T_t	70 to 100°F	copper-constantan thermocouple	±5.0°F

TABLE 3
SUMMARY OF TEST DATA

$\gamma = 1.4$

Config Code	p_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
1	40.15	145	—	.0110	.0339	.152	.153	No second throat
	39.40	122		.0110	.0340	.152	.153	
	35.10	127		.0109	.0342	.152	.153	
	29.80	130		.00957	.0334	.151	.151	
	24.90	132		.00946	.0329	.150	.151	
	19.85	133		.0109	.0330	.149	.150	
	14.95	129		.0127	.0332	.148	.150	
	10.10	129		.0148	.0335	.146	.150	
	5.10	124	—	.0182	.0347	.149	.154	
1-1a	38.85	80	0	.0208	.0342	.207	.207	
	38.75	104	.33	.0208	.0343	.190	.190	
	38.45	138	.48	.0113	.0343	.115	.169	$(X/D)_{min}$
	38.65	108	.66	.0114	.0343	.177	.177	
	38.65	108	1.00	.0114	.0343	.179	.179	$(X/D)_{opt}$
	38.55	113	1.33	.0113	.0344	.172	.172	
	38.55	117	1.66		.0343	.171	.171	
	38.55	122	1.99			.172	.177	
	38.45	130	2.16			.168	.168	
	38.45	133	2.24			.166	.168	$(X/D)_{max}$
	38.55	127	2.33	.0113	.0343		.177	Would not restart
	19.85	136	0	.0188	.0327	.203	.203	
	19.70	133	.33	.0177	.0329	.185	.185	
	19.75	132	.46	.0116	.0329	-	-	Would not restart
	19.75		.47	.0116	.0329	-	.167	$(X/D)_{min}$, Would not restart
	19.70		.66	.0116	-	-	-	
	19.45		.66	.0117	.0329	.173	.173	
	19.25		2.16	-	-	-	-	$(X/D)_{max}$, Would not restart
	19.75		2.16	.0116	.0329	-	-	
	19.25		2.24	-	-	-	-	
	19.75	132	2.33	-	-	-	-	Would not restart
1-2a	39.90	105	.33	.0243	.0355	.189	.190	
	39.90	107	.44	.0111	.0354	.167	.167	$(X/D)_{min}$
	39.85	117	.67			.167	.167	
	39.85	115	1.83			.169	.170	$(X/D)_{opt}$
	39.90	111	1.00			.166	.166	
	39.85	115	1.17			.164	.165	
	39.85	113	1.33			.163	.163	
	39.85	111	1.99		.0354	.157	.158	
	39.85	103	2.99		.0355	.146	.160	
	39.80	119	3.99		.0354	.145	.151	
	39.80	119	5.98		.0354	.146	.147	
	39.80	120	7.15	.0111	.0354	.144	.146	

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	P_{pt}, psia	T_t, °F	X/D_d	P_c/P_{pt}	P_{ne}/P_{pt}	P_{ex}/P_{pt} Starting	P_{ex}/P_{pt} Operating	Remarks
1-2a Con't	20.00	118	.33	.0204	.0346	.174	.174	
	19.90		.42	.0108	.0347	.160	.160	$(X/D)_{min}$
			.67			.165	.165	
			.75			.165	.166	$(X/D)_{opt}$
			.83			.164	.165	
			1.00			.162	.163	
			1.99			.154	.155	
			3.99			.142	.148	
	19.90		5.98		.0347	.143	.144	
	20.00	118	7.15	.0108	.0346	.142	.143	
1-2b	34.85	92	0	.0329	.0339	-	.010	
	34.85	92	.17	.00273	.0341	-	-	
	36.85	98	.17	.0271	.0339	.214	.214	
		113	.33	.0238	.0342	.208	.208	
		118	.42	.0191	.0339	.206	.206	
		118	.50	.0112	.0339	.199	.199	$(X/D)_{min} = (X/D)_{opt}$
	36.85	127	.66	.0111	.0339	.192	.192	
	36.75	129	.75	.0110	.0340	.190	.193	
	36.75	127	.79	.0110	.0340	.192	.193	$(X/D)_{max}$
	36.85	130	.83	.0110	.0339	-	.197	Would not restart
	36.85	127	1.00	.0111	.0342	-	-	Would not restart
1-3a	39.85	96	.33	.0237	.0349	.217	.217	
	39.95	101	.43	.0201	.0348	.212	.213	
	39.85	103	.45	.0187	.0348	.214	.216	$(X/D)_{min}$
		93	.50	.0532	.0400	.220	.221	$(X/D)_{opt}$
		108	.67	.0527	.0359	-	-	
			.83	.0464	.0356	-	.213	
			1.17	.0464	.0354	.211	.211	
			1.25	.0482	.0359	.208	.208	
	39.85	108	1.67	.0610	.0394	-	.213	
	39.95	113	1.99	.0788	.0551	-	.210	
	39.95		3.99	.150	.143	-	.213	
	39.95		5.98	.151	.144	-	.208	
	19.80		.41	.0184	-	-	.217	
			.42	.0188	-	-	.217	
			.43	.0540	.0558	-	.225	
			.50	.0528	.0539	-	.237	$(X/D)_{opt}$
			.67	.0487	.0490	-	.222	
	19.80		1.00	.0465	.0437	-	.207	
	19.90		1.99	.0874	.0796	-	.206	
	19.90	113	5.98	.148	.137	-	.211	

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	p_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
1-3b	39.85	105	.33	.0233	.0349	.243	.243	
	39.75	118	.42	.0191	.0350	.237	.238	
	39.65	118	.44	.0179	.0338	.231	.231	$(X/D)_{min} = (X/D)_{opt}$
		135	.51	.0530	.0401	.247	.247	
		137	.67	.0490	.0369	.247	.247	
		141	1.00	.0459	.0356	.246	.246	
		145	1.33	.0502	.0367	.237	.237	
		146	1.99	.0820	.0562	.199	.199	
		149	2.99	.155	.148	.156	.156	
	39.65	149	3.99	.163	.155	.156	.156	
	19.95	146	.33	.0201	.0339	.218	.218	
	19.85	145	.38	.0203	.0340	-	-	$(X/D)_{min} = (X/D)_{opt}$
	19.95	144	.40	.0191	.0338	.231	.231	
	19.90	145	.46	.0533	.0555	[illegible]	.241	
		144	.50	.0528	.0548	.241	.241	
		145	1.00	.0465	.0438	.236	.236	
			1.99	.0864	.0791	.187	.193	
			2.99	.160	.147	.156	.156	
	19.90	145	3.99	.162	.149	.151	.151	
1-3c	39.80	89	0	.0769	.0528	-	.246	
	39.85	124	.083	.0738	.0552	-	-	
		124	.17	.0708	.0499	-	-	
		127	.25	.0683	.0459	-	-	
		127	.29	.0670	.0419	-	-	
		118	.33	.0662	.0427	.248	.248	
		124	.42	.0733	.0487	.248	.248	
		127	.46	.0770	.0532	.263	.263	
		100	.50	.0790	.0555	.256	.256	
		108	.85	.118	.114	.258	.258	
	39.85	127	1.00	.130	.123	.263	.263	
	39.70	117	2.24	.209	.199	.277	.277	
	39.75	120	3.99	.235	.221	.259	.259	
	20.05	128	.33	.0753	.0693	.234	.234	
	20.05		.50	.0835	.0763	.248	.248	
	19.90		.67	.105	.0975	.251	.251	
	19.90		.83	.130	.119	.256	.256	
	20.10	128	1.00	.161	.149	.259	.264	
	19.90	129	1.99	.224	.209	.264	.264	
	19.90	129	3.99	.234	.217	.259	.259	
1-4a	39.15	120	.75	.0312	.0342	.163	.166	
	39.15	113	.75	.0112	.0342	-	-	
	39.15	113	.79	.0112	.0342	.125	.169	$(X/D)_{min}$

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	p_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
1-4a Con't	39.15	132	1.00	.0111	.0337	.180	.181	
			1.17			.182	.183	
			1.25			.183	.183	$(X/D)_{opt}$
			1.33			.182	.183	
		132	1.66			.151	.177	
		127	1.91			-	.175	$(X/D)_{max}$
		127	1.95			-	.175	Would not restart
		127	1.99			-	.173	Would not restart
	39.15	132	2.99	.0111	.0337	-	.169	Would not restart
	19.80	134	.58	.0296	-	-	-	
	19.80	132	.75	.0340	.0468	.158	.176	
	19.80	134	.83	.0112	.0331	.169	.170	$(X/D)_{min}$
	19.85	132	.92		.0330	.174	.175	
	19.85	132	1.00			.179	.180	$(X/D)_{opt}$
	19.85	132	1.08			.179	.180	
	19.90	134	1.25			.177	.178	
	19.85	132	1.33		.0330	.176	.177	
	19.80		1.50		.0331	.149	.173	$(X/D)_{max}$
	19.80		1.54		.0331	-	-	Would not restart
	19.80	132	1.99	.0112	.0331	-	.168	Would not restart
3	46.90	84	-	.00186	.00592	.0536	.0537	
	40.00	84		.00209	.00595	.0546	.0546	
	35.15	84		.00238	.00592	.0535	.0535	
	30.10	87		.00302	.00594	.0528	.0537	
	24.65	87		.00392	.00592	.0515	.0540	
	20.15	89		.00424	.00614	.0536	.0538	
	15.08	90		.00436	.00552	.0554	.0555	
	12.30	90	-	.00440	.00653	.0555	.0555	
3-1a	39.95	99	.50	.00232	.00588	.0451	.0582	
	40.00	94	.52	.00198	.00588	-	-	$(X/D)_{min}$
	40.05	94	.52	.00204	.00587	.0587	.0594	
	39.85	86	.83	.00199	.00587	.0595	.0597	
	39.75	118	.92	.00209	.00591	.0599	.0604	
		118	1.00			.0613	.0614	
		120	1.08			.0614	.0616	$(X/D)_{opt}$
	39.75	118	1.17	.00209	.00591	.0604	.0606	
	39.85	109	1.33	.00204	.00590	.0595	.0597	
		109	1.50	.00204		.0590	.0592	
		102	1.66	.00201		.0575	.0577	
		205	1.99	.00201		.0565	.0567	
		109	2.99	.00204		.0562	.0565	
		111	3.99	.00206		.0537	.0540	
	39.85	113	4.66	.00206	.00590	.0487	.0502	$\sim (X/D_d)_{max}$

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	p_{t}, psia	T_t, °F	X/D_d	p_c/p_{t}	p_{ne}/p_{t}	p_{ex}/p_{t} Starting	p_{ex}/p_{t} Operating	Remarks
3-1a Con't	39.85	118	4.82	.00206	.00590	-	-	Would not restart
	40.15	99	0	.00383	.00581	-	.0707	
	40.15	103	.33	.00337	.00576	-	.0651	
	40.00	108	.86	.00239	.00576	-	.0591	
	40.00	108	.64	.00239	.00576	.0588	.0591	~$(X/D_d)_{min}$
	40.00	118	1.0	.00239	.00578	.0605	.0605	
	40.00	122	3.99	.00242	.00578	.0540	.0548	
	39.85	132	4.28	.00245	.00580	.0508	.0531	
	39.85	132	4.32	.00245	.00580	.0479	.0530	~$(X/D_d)_{max}$
	39.85	132	4.49	.00245	.00580	-	.0517	Would not restart
	40.00	122	5.98	.00239	.00578	-	.0460	Would not restart
	19.90	136	0	.00734	.00671	.0693	.0693	
		132	.33	.00637	.00612	.0613	.0643	
			.46	.00607	.00612	.0613	.0643	
			.64	.00588	.00612	.0633	.0633	
	19.90	132	1.00	.00452	.00583	.0585	.0585	
3-2a	39.85	99	.30	.00447	.00614	.0647	.0660	
		100	.47	.00238		.0605	.0605	
		102	.49	.00201		.0592	.0592	
		103	.55	.00201		.0582	.0582	
	39.85	105	.64	.00201	.00614	.0572	.0572	
	39.95	90	.97	.00199	.00620	.0558	.0558	
	39.85	105	1.30	.00201	.00614	.0567	.0567	
		105	1.47	.00201	.00614	.0565	.0565	
		105	1.63	.00201	.00614	.0562	.0562	
		94	1.96	.00199	.00621	.0548	.0548	
		94	2.96		.00621	.0542	.0542	
		94	3.96		.00612	.0535	.0535	
		95	5.95		.00619	.0517	.0517	
	39.85	96	7.11	.00199	.00614	.0517	.0517	
	19.95	105	.64	.00582	.00648	.0584	.0584	
	19.95	102	.80	.00436	.00648	.0541	.0541	
	19.90		1.14	.00428	.00649	.0548	.0548	
	19.90		1.30	.00428	.00649	.0578	.0578	$(X/D_d)_{opt}$
	19.90		1.39	.00428	.00649	.0558	.0558	
	19.95	105	1.47	.00427	.00648	.0561	.0561	
	19.90	103	3.96	.00428	.00649	.0543	.0543	
	19.90	103	5.95	.00428	.00649	.0525	.0525	
3-2b	44.15	84	0	.00616	.00588	.0818	.0818	
	43.95		.33	.00455	.00586	.0683	.0683	
	43.85		.50	.00190	.00592	.0629	.0629	~$(X/D)_{min}$
	43.75		.66	.00186	.00581	.0615	.0615	
	43.55		1.00	.00187	.00582	.0608	.0608	
	43.55	84	1.33	.00187	.00582	.0620	.0620	$(X/D)_{opt}$

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	P_{pt}, psia	T_t, °F	X/D_d	P_c/P_{pt}	P_{ne}/P_{pt}	P_{ex}/P_{pt} Starting	P_{ex}/P_{pt} Operating	Remarks
3-2b Con't	43.35	84	1.66	.00187	.00582	.0579	.0586	
	43.35	76	1.99	.00188	-	-	.0574	
	43.55	76	1.99	.0119	-	.0574	-	
	43.30	76	1.99	.0120	-	.0573	-	
	43.95	84	3.99	.0146	-	-	.0123	Would not restart
	29.90	74	1.99	.00239	.00569	.0579	.0582	
	24.80			.00337	.00565	-	-	
	19.92			.00398	.00549	.0585	.0648	
	9.08	74	1.99	.00447	.00652	.0575	.0664	
3-3a	40.00	88	.50	.00266	.00600	.0693	.0695	
	39.75	88	.53	.00200	.00591	-	.0674	$(X/D_d)_{min} = (X/D_d)_{opt}$ (Would not restart)
	39.85	90	.54	.00199	.00590	.0675	.0678	
	39.79	98	.66		.00591	.0669	.0671	
			.83			.0648	.0651	
			1.00			.0631	.0633	
	39.79	98	1.08		.00591	.0653	.0656	
	39.85	92	1.14		.00590	(.0640)(.0652)	.0658	$(X/D_d)_{max}$
	39.85	90	1.33	.00199	.00590	-	-	Would not restart
	19.75	98	.83	.00509	.00588	.0628	.0633	
		100	.87	.00441	.00588	.0638	.0643	$(X/D_d)_{min} = (X/D_d)_{opt}$
			1.00	.00431	.00588	.0628	.0633	
			1.16	-	-	-	.0547	Would not restart
			1.33	-	-	.0343	.0522	$(X/D_d)_{max}$
	19.75	100	1.66	-	-	-	.0633	Would not restart
3-3b	40.05	86	.30	.00430	.00598	.0915	.0916	
	40.05	90	.49	.00199	.00594	.0819	.0821	$(X/D_d)_{min}$
	40.10	96	.64	.00200	.00595	.0853	.0854	
	40.00		.80	.00206	.00594	.0870	.0873	
	40.10		.87	.00186	.00595	.0872	.0875	$(X/D_d)_{max} = (X/D_d)_{opt}$
	40.10		.89	.00186	.00595	-	-	Would not restart
	19.75		.64	.00583	-	.0891	.0896	
	19.75		.97	.00411	-	-	.0876	
	19.75	96	1.14	.00411	-	-	-	
3-3c	39.60	96	.33	.00425	.00603	.0816	.0816	
	39.60	102	.48	.00378	.00581	-	.0722	$(X/D_d)_{min} = (X/D_d)_{opt}$ (Would not restart)
	39.55	113	.49	.0152	.0127	.0910	.0910	
	39.45	119	.89	.0110	.00985	.0778	.0781	
		120	.98	.0171	.0133	.0798	.0798	
		122	1.23	.0169	-	-	-	
		124	1.27	.0266	.0233	.0816	.0816	
		127	1.99	.0446	.0401	.0824	.0824	
	39.45	132	3.99	.0644	.0580	.0824	.0824	

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	P_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
3-3c Con't	39.45	132	5.98	.0649	.0588	.0824	.0824	
	19.80	130	.17	.0969	-	.0818	.0818	
		130	.33	.00718	.00689	.0768	.0768	
		130	.42	.00684	-	-	-	
		128	.46	.00664	.00645	.0753	.0760	
			.52	.00645	-	-	-	$(X/D)_{min} = (X/D)_{opt}$
	19.80		.52	.0157	.0136	.0758	.0758	
	19.85		1.00	.0117	.0116	.0720	.0720	
	19.80		1.10	.0105	-	-	-	
	19.80		1.25	.0133	.0135	.0737	.0737	
	19.85	128	1.99	.0208	.0195	.0756	.0756	
	19.95	132	5.98	.0607	.0571	.0752	.0752	
3-4a	40.05	90	.47	.00522	.00587	.0649	.0649	
	40.00	94	.50	.00213	.00588	.0618	.0618	
	39.85	87	.64	.00207	.00587	.0587	.0590	
	39.95	99	.80	.00218	.00588	.0568	.0568	
	40.00	96	.97	.00218	.00588	.0561	.0561	
	39.85	100	1.30	.00223	.00590	.0592	.0592	
	39.80	103	1.63	.00221	.00588	.0601	.0601	
	39.80	108	1.79	.00224		.0616	.0617	$(X/D_d)_{opt}$
	39.80	108	1.88	.00224		.0613	.0613	
	40.00	96	1.96	.00213		.0608	.0608	
	39.80	108	2.13	.00224		.0585	.0601	
	39.80	106	2.29	.00223		.0580	.0590	
	39.7	113	2.96	.00225	.00587	.0514	.0518	
	40.00	116	3.46	.00223	.00585	.0518	.0520	
	40.00	116	3.79	.00223	-	-	-	
	40.00	116	3.96	.00223	.00585	-	.0500	
	20.17	115	.80	.00529	.00609	.0560	.0560	$(X/D_d)_{min}$
		115	.82	.00430	.00599	.0545	.0545	$(X/D_d)_{min}$
		113	.97		.00595	.0530	.0530	
		113	1.96		.00595	.0605	.0605	
	20.17	115	2.13	.00430	.00595	.0600	.0610	
	20.12		2.29	.00431	.00596	.0582	.0636	$(X/D_d)_{opt}$
	20.12		2.46	.00431	.00596	.0572	.0626	
	20.12	115	2.63	.00431	.00596	.0557	.0606	
	20.17	116	2.96	.00430	.00599	.0526	.0545	
	20.17	116	3.46	.00430	.00599	.0521	.0526	
	20.12	115	3.96	.00431	.00596	-	.0517	
	20.12		4.29	-	-	-	-	Restarted o.k.
	20.07		4.46	.00432	.00598	.0399	.0593	$(X/D_d)_{max}$
	20.12		4.79	-	-	-	-	Would not restart
	20.12	115	5.95	-	-	-	-	Would not restart

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	P_{pt}, psia	T_t, °F	X/D_d	P_c/P_{pt}	P_{ne}/P_{pt}	P_{ex}/P_{pt} Starting	P_{ex}/P_{pt} Operating	Remarks
4	45.45	84	-	.00106	.00134	.0239	.0239	No second throat
	39.70	84		.00117	.00142	.0231	.0231	
	36.45	82		.00125	.00154	.0247	.0247	
	29.70	80		.00150	.00189	.0248	.0248	
	26.70	82	-	.00160	.00210	.0252	.0252	
4-1a	42.60	74	0	.00157	.00179	-	-	
	40.00	80	0	.00164	.00162	.0309	.0309	
	39.85	84	.33	.00148	.00155	.0273	.0283	
	40.05	84	.66	.00147	.00152	.0272	.0282	
	40.05	86	.77	.00110	.00147	.0256	.0256	$(X/D_d)_{min}$
	40.10	84	1.00	.00109	.00150	.0262	.0262	
	40.35	86	5.31		.00146	.0236	.0236	
	40.35	86	5.98		.00146	-	-	Would not restart
	40.20	86	6.64	.00109	.00147	.0183	.0231	$\sim(X/D_d)_{max}$
	20.2	94	0	.00294	.00292	.0316	.0318	
	20.15	94	.33	.00249	.00293	.0307	.0308	
	20.15	89	.66	.00219	.00262	.0296	.0297	
	20.15		1.17	.00156	.00193	.0285	.0286	$(X/D_d)_{min}$
	20.10		1.33	.00154	.00223	.0281	.0281	
	20.15		5.98	.00156	.00193	.0232	.0232	
	20.15	89	6.31	.00156	.00193	.0226	.0226	
	40.21	81	.70	.00102	-	-	-	$(X/D_d)_{min}$
	40.21	81	.70	.00121	.00148	.0261	.0264	
	40.05	81	.83	.00102	.00155	.0260	.0262	
	40.20	83	1.33	.00106	.00149	.0259	.0261	
	40.20	83	1.83		.00149	.0254	.0259	
	40.21	81	2.00		.00154	.0264	.0266	
	40.20	83	2.17		.00149	.0263	.0266	
	40.21	81	2.33			.0264	.0266	
	40.20	83	2.50			.0264	.0266	$(X/D_d)_{opt}$
		83	2.67			.0261	.0264	
		83	3.00			.0259	.0261	
		85	4.00			-	.0251	
	40.20	85	5.67	.00106	.00149	.0204	.0219	
4-1b	39.95	74	2.33	.00104	.00150	.0272	.0273	
4-2a	39.65	74	.50	.00161	.00154	.0265	.0265	
	39.85		.65	.00107	.00146	.0250	.0250	$(X/D_d)_{min}$
	39.75		1.00	.00105	.00151	.0245	.0245	
	39.85		1.33	.00107	.00146	.0248	.0248	
	39.85		1.83		.00146	.0251	.0251	
	39.90		1.99		.00150	.0251	.0251	$(X/D_d)_{opt}$
	39.60	74	2.16	.00107	.00147	.0246	.0246	

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	p_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
4-2a Con't	39.85	74	2.32	.00107	.00146	.0239	.0239	
	39.85		2.99	.00104		.0242	.0242	
	39.85		3.99	.00104		.0241	.0241	
	39.75		5.98	.00105	.00146	.0234	.0234	
	39.75	74	7.14	-	-	-	-	Restarted
	26.08	72	.98	.00151	.00165	.0234	.0245	$(X/D_d)_{min}$
	26.18		1.00	.00150		.0233	.0244	
	26.18		1.99	.00150		.0248	.0248	
	26.18	72	3.99	.00150	.00165	.0238	.0238	
4-2b	39.65	113	0	.00288	.00263	.0362	.0362	
	39.65	113	.33	.00215	.00200	.0300	.0300	
	39.45	84	.54	.00196	.00201	-	.0224	
	39.60	113	.66	.00171	-	.0280	.0280	$(X/D_d)_{min}$
	39.65	92	.83	.00123	.00166	.0271	.0271	
		94	1.99	.00123	.00176	.0281	.0288	~ $(X/D_d)_{opt}$
		94	2.99	.00122	.00163	.0255	.0255	
		94	3.16	.00127		.0197	.0197	$(X/D_d)_{max}$
		108	3.24	.00124		-	.0288	
		108	3.32	.00124		-	.0288	
		94	3.49	.00124	.00163	-	.0197	Would not restart
	39.65	94	3.99	-	-	-	-	Would not restart
	46.90	87	1.00	.000989	.00140	.0252	.0252	
	23.70	113	0	.00416	.00433	.0335	.0406	
	23.64	113	.33	.00335	.00385	.0333	.0333	
	23.64	113	.66	.00577	.00540	.0322	.0322	
	23.90	79	1.00	.00186	.00231	.0262	.0262	$(X/D_d)_{min}$
	23.64	113	1.00	.00610	-	-	-	
	23.90	79	1.99	.00158	.00198	.0284	.0293	
	23.90	79	2.99	.00158	.00198	.0262	.0303	
4-3a	40.00	89	.66	.00155	.00165	.0278	.0280	
	39.90		.77	.00138	.00162	.0300	.0302	$(X/D_d)_{min} = (X/D_d)_{opt}$
	39.90		.79	.00138	.00162	.0298	.0300	
	40.10	89	.83	.00136	.00166	.0295	.0296	
	39.85	90	.91	.00139	.00163	.0286	.0289	
	39.90	81	1.00	.00136	.00170	.0285	.0288	
	39.95	84	1.08	.00136	.00166	.0285	.0288	
	39.75		1.16	.00137	.00166	.0285	.0288	
	40.05		1.25	.00136	.00165	.0287	.0290	
	39.70		1.33	.00137	.00167	.0285	.0293	
	39.90		1.41	.00136	.00166	.0271	.0293	
	39.75		1.45	.00137	.00166	.0214	.0294	$(X/D_d)_{max}$
	39.75	84	1.50	.00137	.00166	-	.0294	Would not restart

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	P_{pt}, psia	T_t, °F	X/D_d	P_c/P_{pt}	P_{ne}/P_{pt}	P_{ex}/P_{pt} Starting	P_{ex}/P_{pt} Operating	Remarks
4-3a Con't	39.95	81	1.99	.00136	.00166	-	-	Would not restart
	39.80	81	1.99	.00136	.00166	-	.0294	Would not restart
	39.85	90	3.99	-	-	-	-	Would not restart
	19.85	88	1.00	.00185	.00245	-	-	
		87	1.16	.00191	.00245	.0302	.0304	$(X/D_d)_{min} = (X/D_d)_{opt}$
		90	1.33	.00185	.00267	.0238	.0241	
		88	1.99		.00267	.0268	.0300	
		88	2.99		.00245	-	-	Would not restart
	19.85	88	3.99	.00185	.00245	-	-	Would not restart
4-3b	39.90	76	.58	.00142	.00162	.0386	.0386	
	39.85	78	.65	.00107	.00163	.0371	.0374	$(X/D_d)_{min}$
	39.95	74	.67	.00106	.00164	.0373	.0375	
	39.80	79	1.00	.00102	.00163	.0393	.0395	
		80	1.33			.0410	.0411	
		79	1.33			.0410	.0411	$(X/D_d)_{max} = (X/D_d)_{opt}$
			1.35			-	-	Would not restart
			1.38			-	-	
			1.42			-	.0415	
			1.50			-	.0425	
	39.80	79	1.66			-	-	
	39.75	80	3.32	.00102	.00163	-	-	Would not restart
	19.85	80	1.00	.00180	.00216	.0403	.0407	
		79	1.04	.00156		.0405	.0405	$(X/D_d)_{min}$
		79	1.33	.00151		.0420	.0423	
	19.85	80	1.99	.00151	.00216	.0429	.0459	
	15.00	80	1.99	-	-	-	.0456	
4-3c	39.60	82	0	.00242	.00235	.0352	.0354	
	39.45	82	.17	.00207	.00203	.0350	.0352	
	39.40	84	.62	.00152	.00172	.0325	.0325	
	39.40	84	.66	.00133	.00237	.0317	.0317	$(X/D_d)_{min} = (X/D_d)_{opt}$
	39.40	86	.70	.00562	.00445	.0381	.0381	
	39.35	94	1.00	.00523	.00438	.0351	.0351	
	39.40	92	1.99	.0115	.0103	.0343	.0343	
	39.40	90	3.99	.0228	.0220	.0350	.0350	
	39.50	90	5.98	.0258	.251	.0353	.0353	
	19.95	89	.17	.00378	.00361	.0369	.0369	
	19.92	89	.42	.00311	.00328	.0355	.0355	
		90	.66	.00264	.00340	.0331	.0331	$(X/D_d)_{min} = (X/D_d)_{opt}$
		94	1.00	.00491	.00456	.0335	.0335	
		89	1.99	.00466	.00443	.0353	.0353	
		89	3.99	.0132	.0128	.0373	.0373	
	19.92	89	5.98	.0230	-	-	-	

TABLE 3 (Continued)

$\gamma = 1.4$

Config Code	p_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
4-4a	40.03	73	.65	.00130	.00159	.0250	.0250	
	40.05	72	.66	.00104		-	-	$(X/D)_{min}$
	40.05		.71	.00104		-	-	
	40.15		.75	.00104	.00159	-	-	
	39.95		.79	.00105	.00160	.0238	.0239	
	40.15	72	.83	.00104	.00159	.0242	.0245	
	40.05	73	1.99	.00106	.00159	.0270	.0270	
	39.85	79	2.15	.00105	-	.0261	.0277	
	39.70	79	2.32	.00105	-	.0258	.0283	
	39.75	79	2.49	.00105	-	.0254	.0277	
	40.05	73	2.99	.00106	.00157	.0240	.0242	
	40.05	74	3.99	.00106	.00157	.0245	.0245	
	40.05	74	4.98	.00106	.00157	.0220	.0222	
	39.85	75	5.07	.00107	.00158	.0206	.0221	
	39.85		5.15		.00158	-	-	$(X/D_d)_{max}$
	39.85		5.23		.00158	-	-	Would not restart
	39.95		5.48		.00157	-	-	
			5.65			-	-	
			5.81			-	-	
	39.95	75	5.98	.00107	.00157	-	-	
	19.90	74	1.00	.00222	.00221	.0262	.0262	
	19.80		1.04	.00182	.00206	.0241	.0253	$(X/D_d)_{min}$
	19.90		1.17	.00151	.00221	.0248	.0250	
	19.95		1.99	.00151	.00202	.0271	.0271	
	19.85		2.49	.00152	.00195	.0269	.0280	
	19.70		2.66	.00153	.00194	.0262	.0299	$(X/D_d)_{opt}$
	19.85		2.82	.00152	.00195	.0259	.0293	
	19.95		2.99	.00151	.00202	.0256	.0285	
	19.95		3.99	.00153	.00207	.0250	.0250	
	20.00	74	5.23	.00153	.00215	.0231	.0231	
5	45.50	89	-	.000344	.00354	.0242	.0263	No second throat
	40.05	89		.000362	.00356	.0240	.0264	
	34.80	87		.000406	.00367	.0239	.0263	
	29.65			.000419	.00368	.0202	.0260	
	19.60			-	-	.0258	.0278	
	12.95	87	-	.000717	-	.0277	.0285	
5-3b	39.95	79	0	.00116	.00353	.0547	.0547	
	39.90	79	.50	.000562	.00349	.0519	.0519	
	39.95	80	.58	.000363	.00351	.0508	.0508	$(X/D_d)_{min} = (X/D_d)_{opt}$
	39.95	80	.67	.000363	.00351	.0510	.0510	
	39.90	80	.83	.000364	.00351	.0508	.0508	
	39.85	77	1.00	.000364	.00352	.0502	.0502	

TABLE 3 (Concluded)

$\gamma = 1.4$

Config Code	p_{pt}, psia	T_t, °F	X/D_d	p_c/p_{pt}	p_{ne}/p_{pt}	p_{ex}/p_{pt} Starting	p_{ex}/p_{pt} Operating	Remarks
5-3b	39.90	80	1.33	.000364	.00351	.0484	.0484	
	39.85	80	1.66	.000364	.00352	.0444	.0444	
	39.75	78	1.99	.000365	.00350	.0347	.0418	
	39.90	79	2.82		.00349	.0253	.0416	(p_c unsteady)
	39.85	80	2.91		.00352	.0206	.0457	(p_c unsteady)$(X/D_d)_{max}$
	39.95	78	2.99		.00349	-	.0456	(p_c unsteady) Would not restart
	19.85	80	.33	.00102	.00376	.0529	.0529	
			.63	.000409		.0499	.0499	$(X/D_d)_{min} = (X/D_d)_{opt}$
			.67			-	.0499	
			.83			.0499	.0499	
			1.00			.0496	.0496	
			1.17			.0489	.0489	
			1.33			.0393	.0471	
			1.99	.000409	.00376	.0317	.0416	
	19.85	80	2.99	-	-	-	-	Would not restart

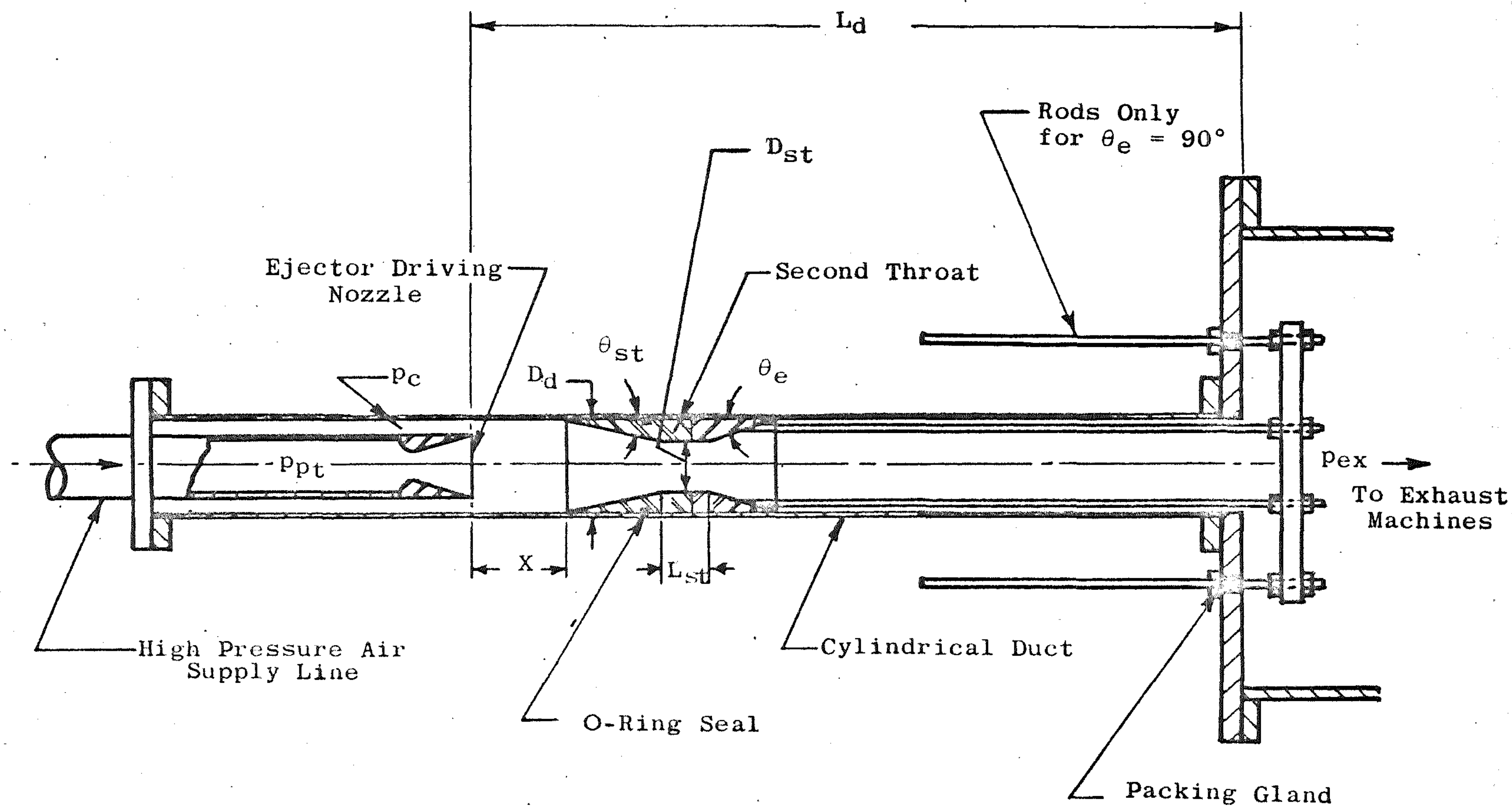
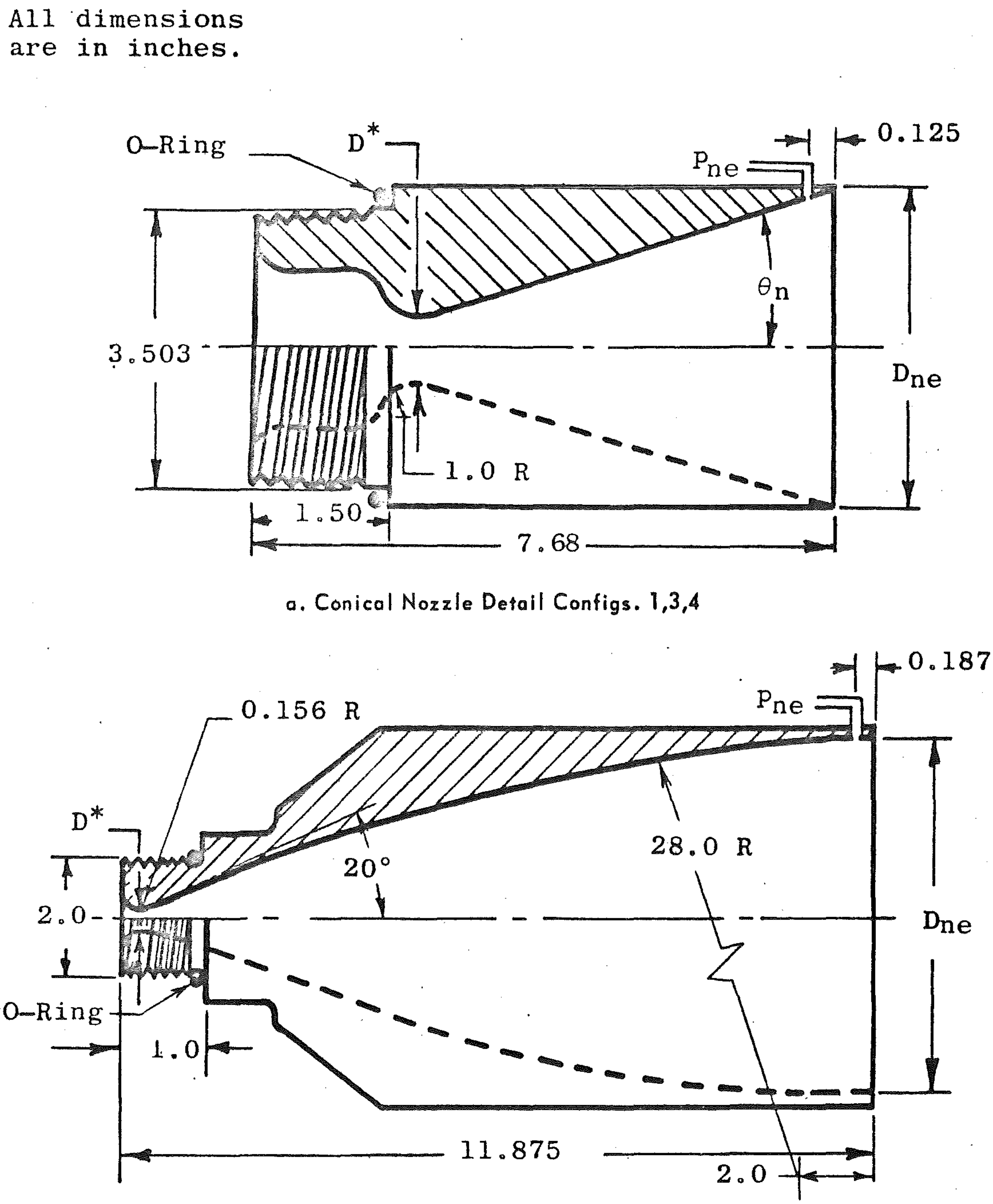


Fig. 1 Typical Ejector Configuration



a. Conical Nozzle Detail Configs. 1,3,4

b. Contour Nozzle Detail Config. 5

Fig. 2 Typical Nozzle Configurations

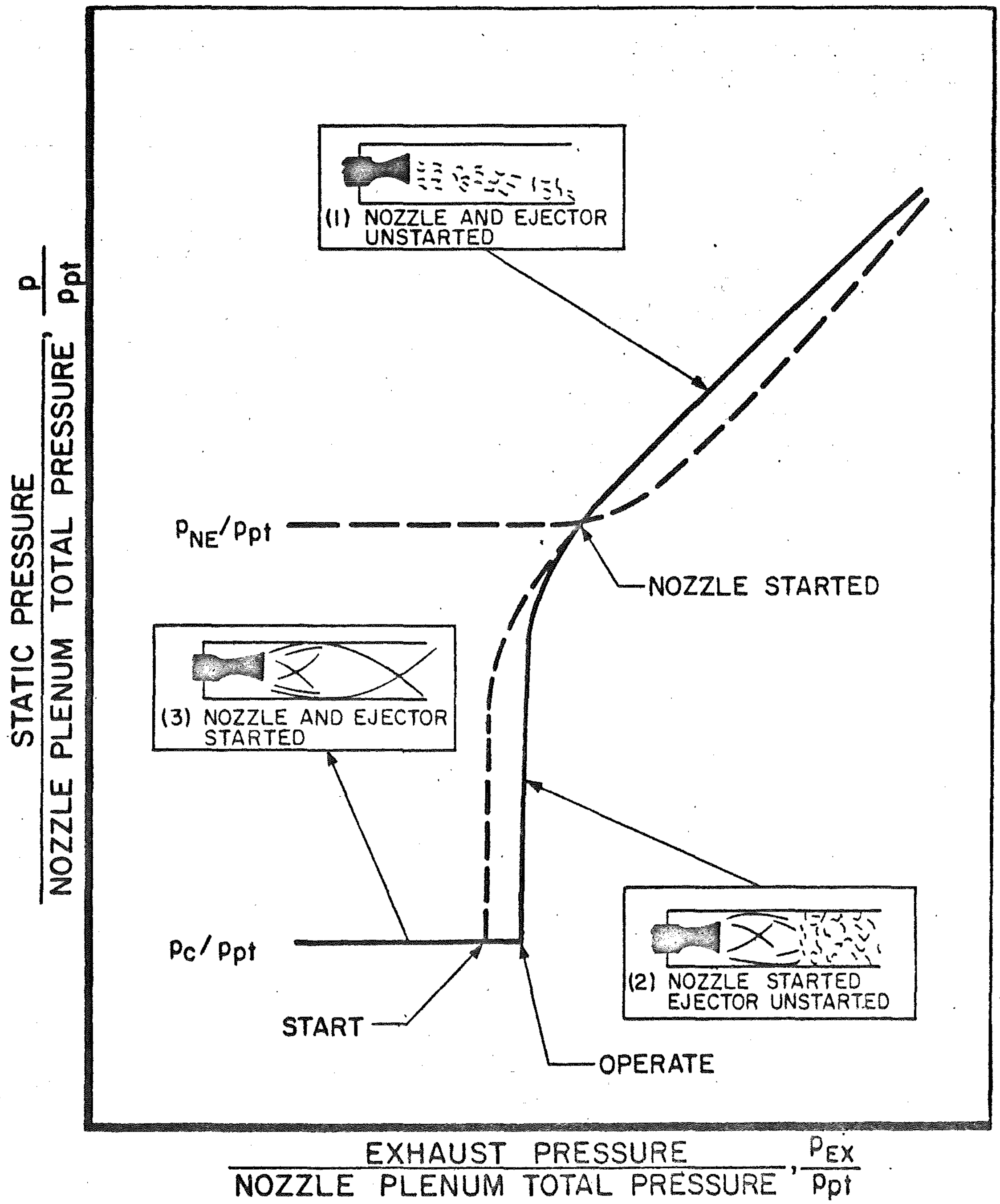
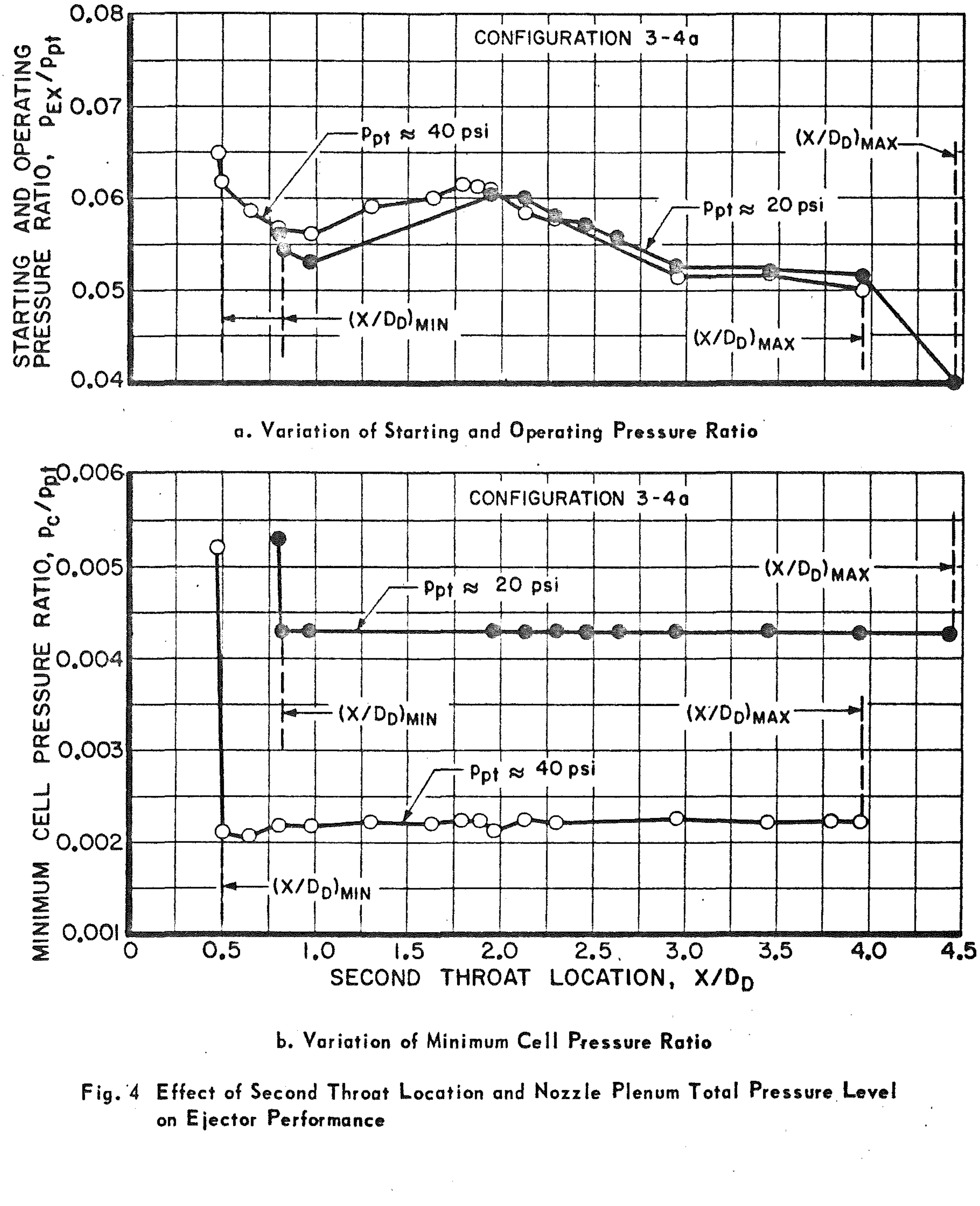


Fig. 3 Typical Ejector Starting Phenomena for Constant Nozzle Plenum Total Pressure



a. Variation of Starting and Operating Pressure Ratio

b. Variation of Minimum Cell Pressure Ratio

Fig. 4 Effect of Second Throat Location and Nozzle Plenum Total Pressure Level on Ejector Performance

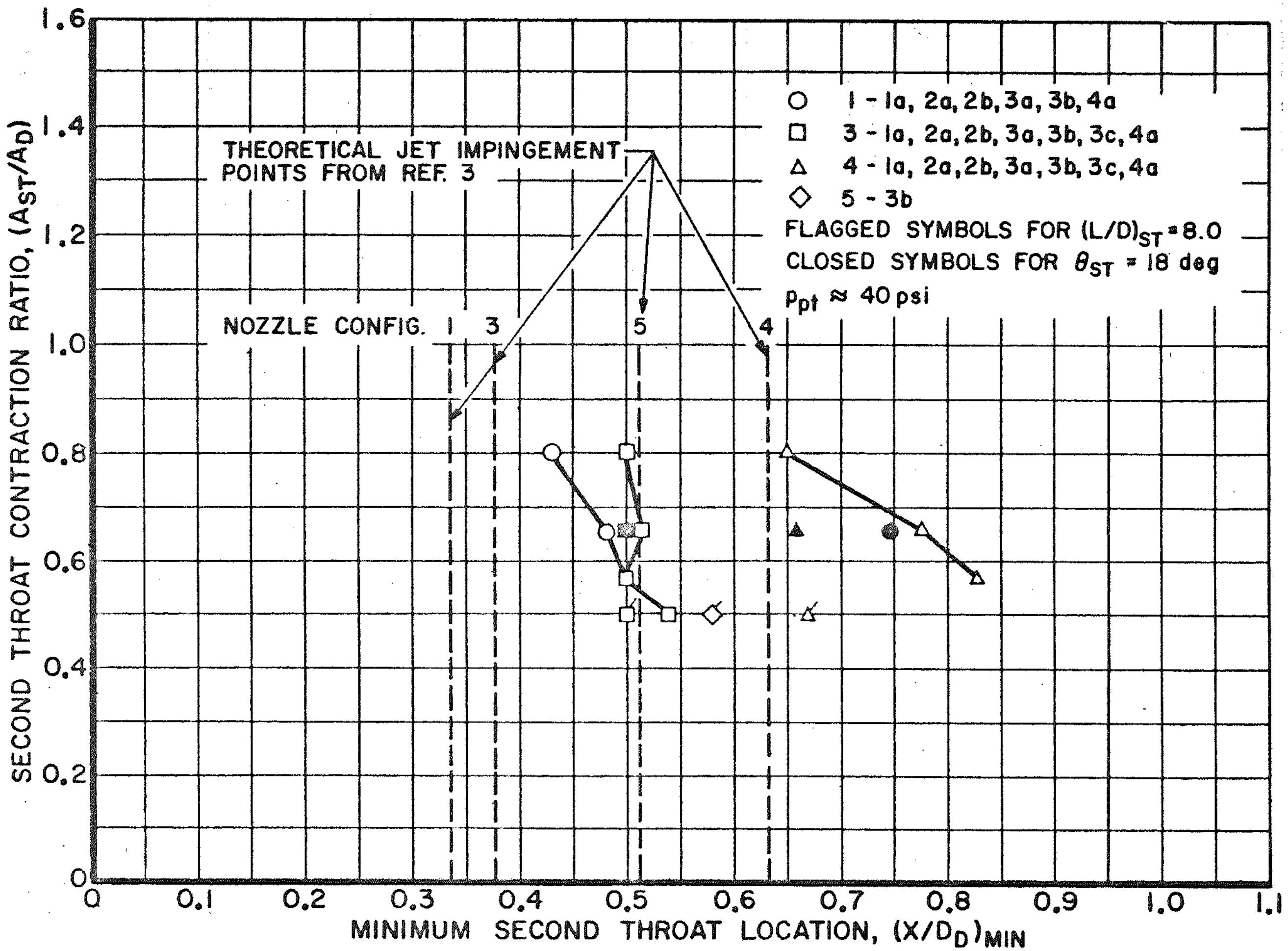


Fig. 5 Comparison of Theoretical Free Jet Impingement Points with $(X/D_d)_{min}$

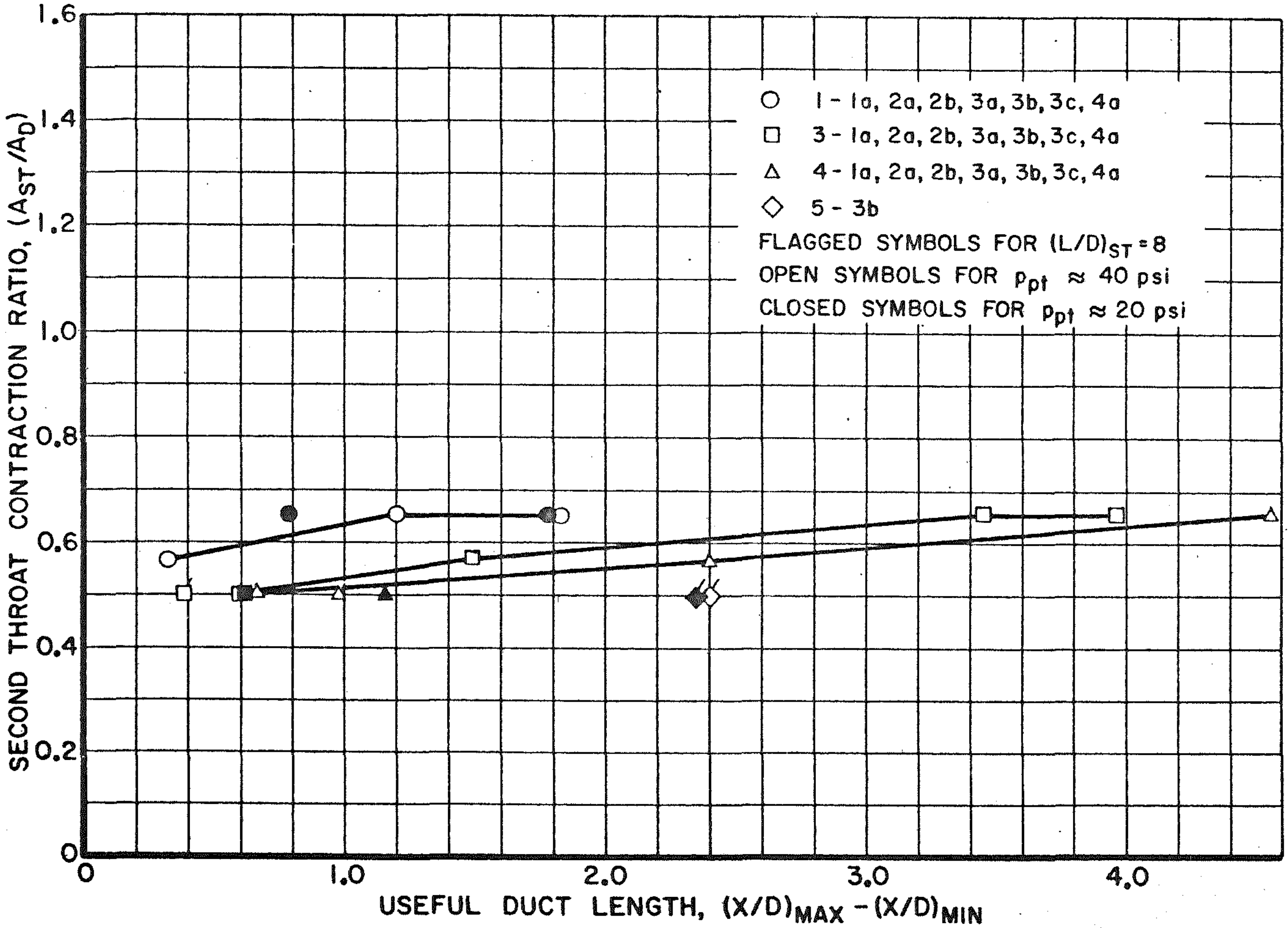


Fig. 6 Variation of Useful Duct Length with Second Throat Contraction Ratio

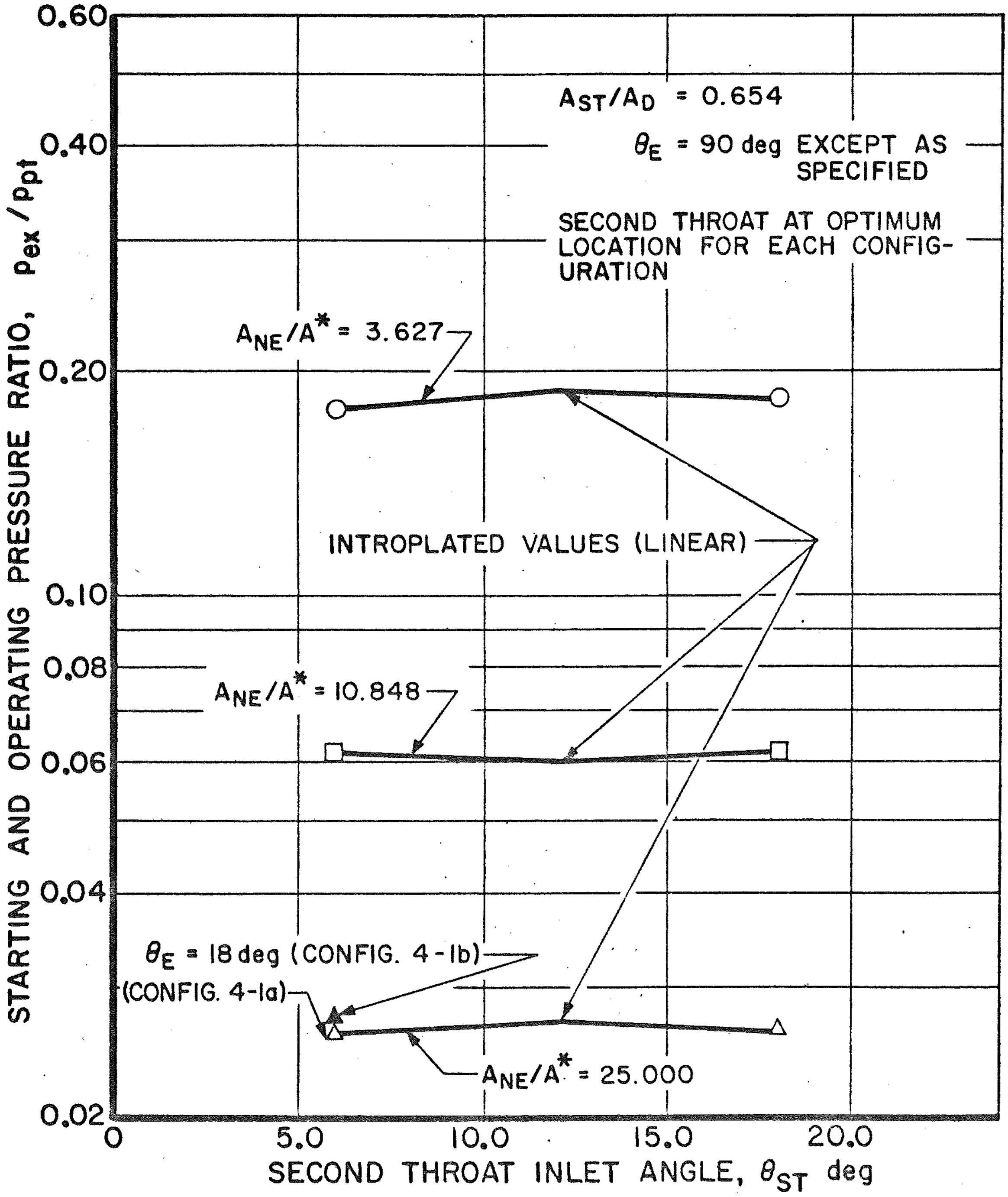
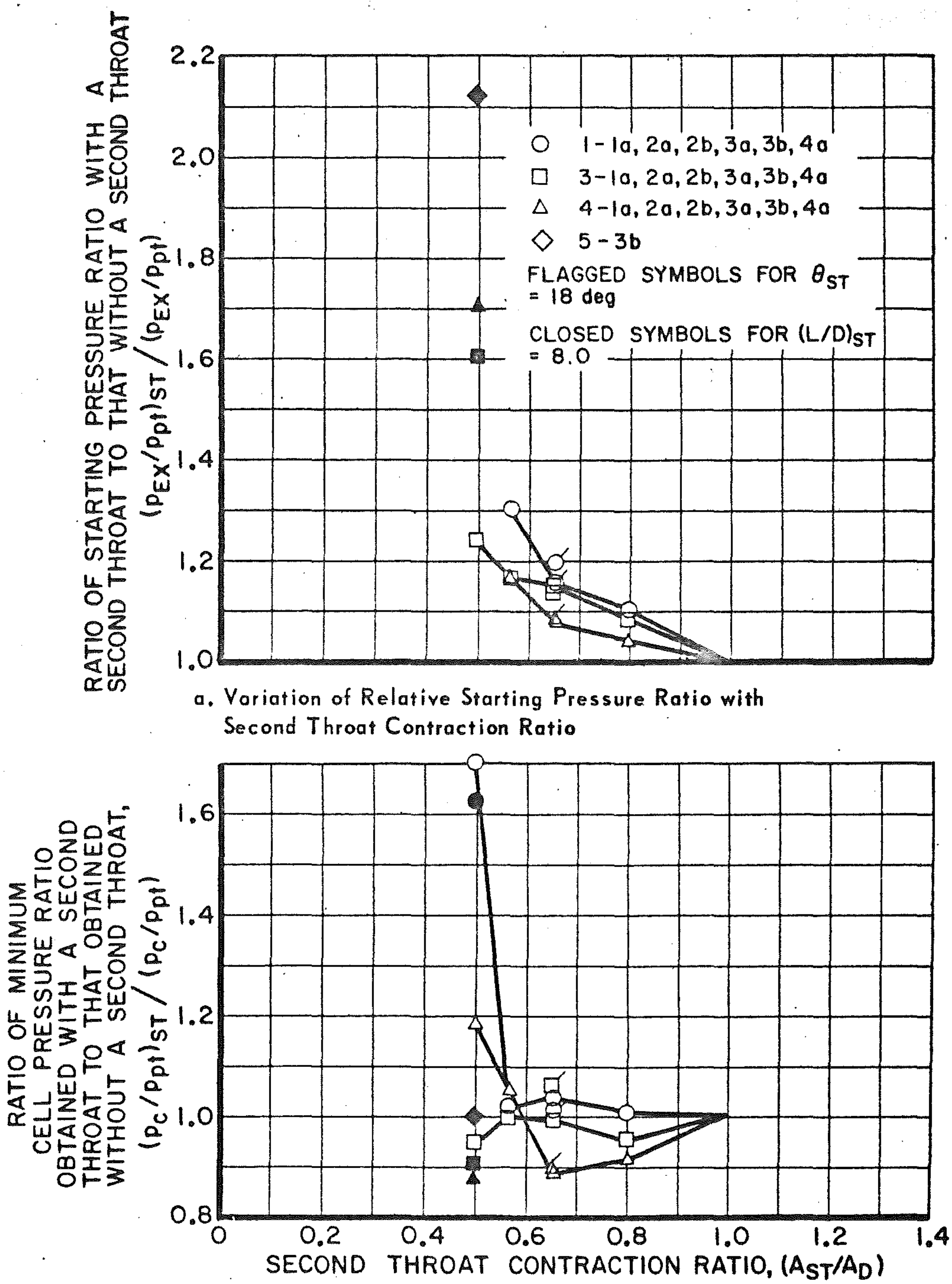


Fig. 7 Effect of Second Throat Inlet Angle and Exit Angle on Ejector Starting and Operating Pressure Ratio



a. Variation of Relative Starting Pressure Ratio with Second Throat Contraction Ratio

b. Variation of Relative Minimum Cell Pressure Ratio with Second Throat Contraction Ratio

Fig. 8 Comparison of Ejector Performance with a Second Throat at Optimum Location to Performance without a Second Throat

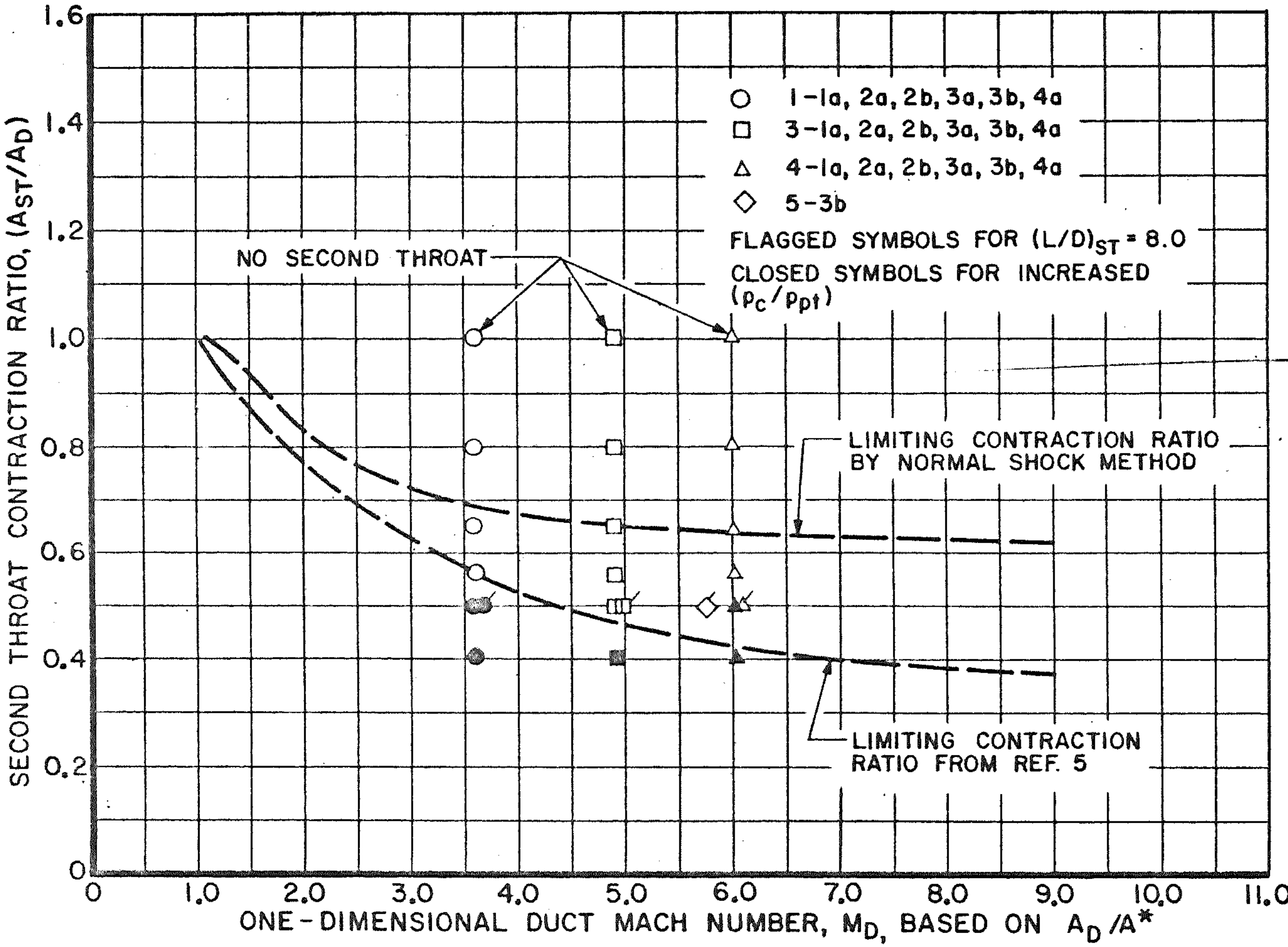


Fig. 9 Comparison of Experimental Results with Limiting Second Throat Contraction Ratio Curve from Ref. 5

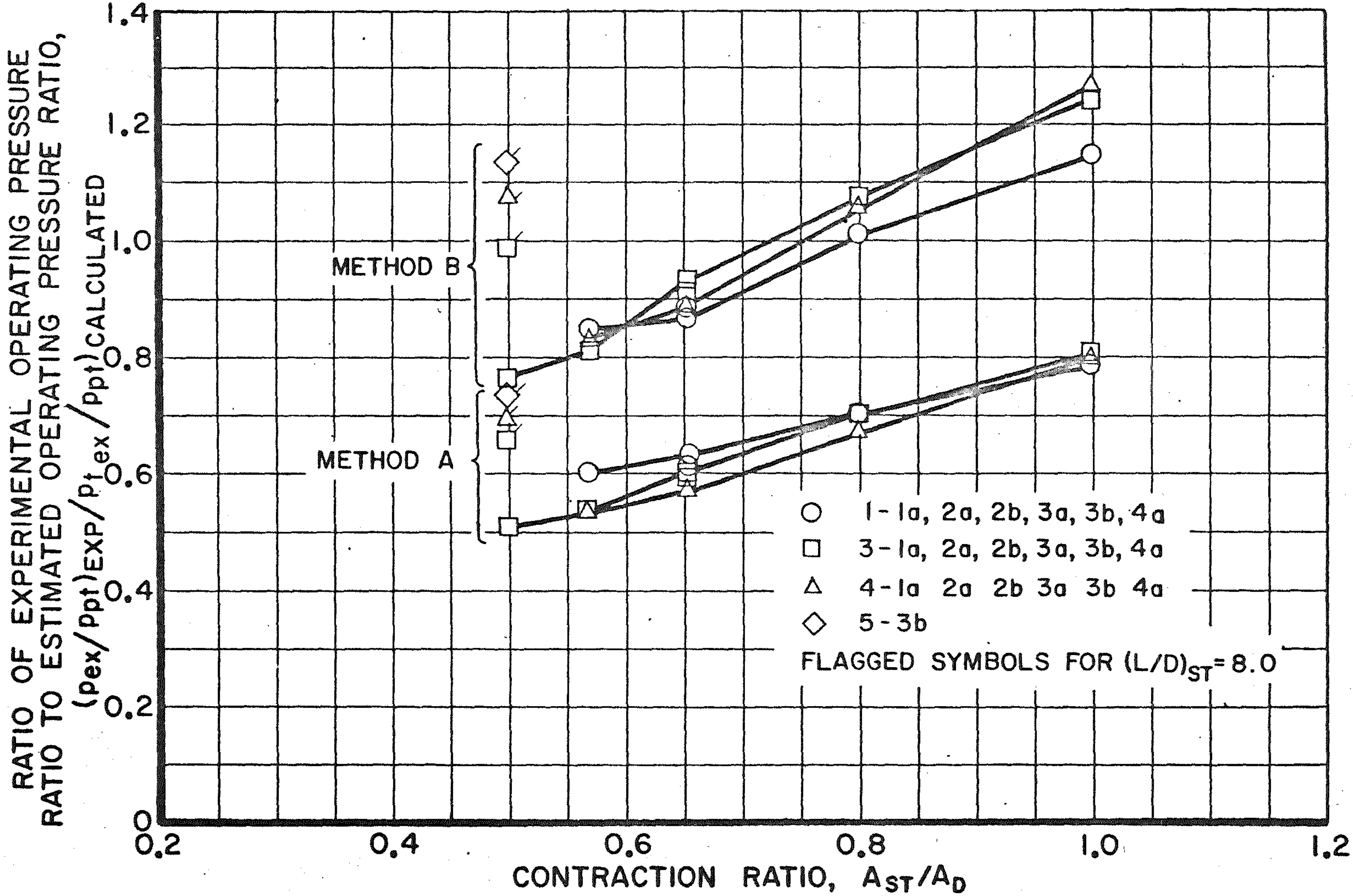


Fig. 10 Comparison of Calculated Operating Pressure Ratio with Experimental Results